INVESTIGATION OF CLOUD PROPERTIES AND ATMOSPHERIC PROFILES WITH MODIS

SEMI-ANNUAL REPORT FOR JANUARY - JUNE 2001

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Contract NAS5-31367

ABSTRACT

In the last six months, UW has identified some problems in the operational algorithms for cloud mask, cloud top properties, and atmospheric profiles, reworked the software, and submitted new versions to SDST for use in processing the MODIS Consistent Year. The Terra eXperiment – 2001 (TX-2001) was conducted out of San Antonio, TX from 14 March to 05 April 2001 and seven missions with the NASA ER-2 aircraft carrying MAS and SHIS instruments underflew Terra. Daily co-located ARM CART and MODIS observations were gathered and water vapor depictions were compared. A Terra Cloud Mask Workshop was hosted by CIMSS 8 – 9 May 2001 and the performance of the MODIS cloud mask was discussed and inter-comparisons of cloud detection by the Terra instruments were organized. The International MODIS and AIRS Processing Package version 1.2 including improved calibration and geo-location algorithms was released 13 April 2001 and a web-site for real time access to SSEC received MODIS data was established.

TASK OBJECTIVES

<u>MODIS Infrared Calibration</u>

Recent MODIS performance assessment at the University of Wisconsin has focused on striping issues in band 26 (1.38µm) and band 34 (13.6µm), mitigating unexpected surface reflectance in band 26 (a possible out-of-band influence), and assessing MODIS radiometric accuracy in thermal IR bands using data from the spring, 2001 TX-2001 ER-2 field campaign. Early MAS comparisons to MODIS suggest that MODIS LWIR window band radiances are slightly cold, but performing near and possibly within their 0.5% accuracy specification, with only small scan mirror angle influence; these and other MODIS bands continue to be assessed with the TX-2001 data set.

<u>Comparison of MODIS Infrared Observations to Calculations</u>

MODIS infrared observations over the ARM CART site in Oklahoma are now routinely extracted from the Level-1B data acquired by direct broadcast at SSEC and compared to forward calculations. Initial results show a strong sensitivity to surface temperature.

<u>MODIS Cloud Mask</u>

Modifications to the MODIS cloud mask were tested and implemented in v3.0.0. These include adjustments to thresholds for snow detection, and for cloud detection over snow and ice covered surfaces. A new processing path for Antarctica during daylight was implemented. Some tests were modified based on elevation information which is now included in the algorithm. The list of ecosystems defined as arid was expanded. A reduction in false cloud identification is seen, particularly in high elevation and arid regions during daylight hours.

MODIS Cloud Top Properties

Version 3.0.0 of the MODIS cloud top properties code was delivered to SDST on 2 May 2001. Significant variability between detectors (striping) in bands 33-36 as well as large random noise in band 34 were leading to incorrect cloud top pressures and cloud effective emissivities. In order to mitigate these problems, minimum cloud signal thresholds (clear minus cloudy radiance values) were raised in bands 31 and 33-36. Efforts are being made to find ways of "de-striping" bands 33-36.

MODIS Atmosphere Profiles

An updated version of the MODIS Atmospheric Profiles retrieval algorithm was delivered to SDST 01 April 2001 to run in the first MODIS Consistent Year processing effort. Problems over the Sahara Desert with unrealistically wet total precipitable water (TPW) retrievals have been diagnosed as being due to non blackbody behavior in the shortwave infrared channels; the regression coefficients were updated to minimize the impact of surface radiation. In order to validate the MODIS atmospheric profile retrievals and to investigate the wet bias of MODIS forward model calculations, the time and space co-located MODIS radiances and Cart Site radiosonde, microwave radiometer, and AERI water vapor profiles have been collected. Initial comparison reveal that there is a consistent bias between MODIS TPW and microwave radiometer water vapor observations. Improvement of the TPW algorithm using Cart Site match-up data and further validation will continue.

Polar Winds

Two case studies have demonstrated the feasibility of deriving tropospheric wind information at high latitudes from polar-orbiting satellites. The methodology employed is based on the algorithms currently used with geostationary satellites, modified for use with the MODIS instrument. Wind vectors (speed, direction, and height) have been estimated for one Arctic and one Antarctic case.

MODIS Direct Broadcast Operations

SSEC collected 1200 Terra MODIS direct broadcast passes by 30 June 2001. Level-1B data and quicklooks are now available on the Internet. Quicklook images from SSEC-acquire MODIS data have been featured on the NASA Earth Observatory. MODIS infrared data over Lake Tahoe are now pushed automatically to Simon Hook at JPL for cloud mask and calibration comparisons with in situ observations.

MODIS Direct Broadcast Software

Version 1.2 of the International MODIS/AIRS Processing Package was released on 13 April 2001. Calibration algorithm and lookup tables were updated to versions 2.5.5 and 2.5.5.1 respectively. In a comparison of one granule of IMAPP versus DAAC Level-1B data, more than 99.96% of the valid pixels matched to one scaled integer or better. The MODIS fire detection group has adopted IMAPP for the Rapid Response System at GSFC.

WORK ACCOMPLISHED

Atmospheric Profiles Science Software

The MODIS Atmospheric Temperature and Moisture Profile Retrieval Algorithm Version 3.0 (for product MOD_PR07) was delivered to SDST on 01 April 2001. Reprocessed and forward processed data using frozen PGEs are planned for the data year Nov 1, 2000 to Oct 31, 2001 to complete the first MODIS Consistent Year. MODIS products including the Atmospheric Profiles will be stored in MODIS Data Collection 003.

Version 3.0 uses an updated set of regression coefficients to improve the water vapor retrieval. Specifically, mixing ratios are now lower than before mitigating a wet bias seen in the previous MODIS moisture retrievals. A check for saturated water vapor mixing ratios was also added. Retrieved values now cannot exceed the saturation value. Previous versions used pressure at mean sea level (PRMSL:MSL) from GDAS1 as ancillary input to the retrieval. Version 3.0 uses surface pressure (PRES:sfc) from GDAS1 instead, which tracks topography effects. In addition, surface pressures are now bilinearly interpolated to MODIS resolution, rather than using the nearest 1 degree resolution value which tended to leave 1 degree artifacts in the retrieved values.

Impact of surface emissivity on the MODIS TPW retrieval

The impact of IR shortwave surface emissivity on the MODIS TPW retrieval over African deserts has been investigated. The operational algorithm is presenting a much wetter TPW in the desert regions, most likely because the surface emissivity at 4.5-micron region is well below blackbody values. Figure 1 shows spectral emissivity for silicates and tilicates (0 – 45-micron particle size) can be as low as 0.3. Figure 2 shows the daytime TPW images of 07 December 2000 from MODIS with the current algorithm (upper panel, bands 24 and 25 are included) and the updated algorithm (lower panel, bands 24 and 25 are not included) over South Africa. Figure 3 is the nighttime TPW from the updated algorithm. Figures 2 and 3 indicate that the atmospheric moisture is more realistic with the updated algorithm. Global TPW retrievals from the updated algorithm are being inspected and plans are to replace the current algorithm in July.

Algorithm improvement and validation using Cart Site matchup data

In order to validate the MODIS atmospheric profile retrievals and to investigate the bias of MODIS forward model calculations, time and space co-located MODIS radiances and ground based atmospheric observations at the Cart Site were collected. The matchup file includes clear-sky cases when MODIS passed over the SGP-CART site with viewing zenith angle less than 40 degrees. MODIS radiances and cloud mask data were obtained through the DAAC and the TPW algorithm (version from 01 April 2001) was run locally on these cases. MODIS shows a consistent moist bias of approximately 3-5 mm when compared to the microwave radiometer (MWR). Figure 4 shows the comparison of MODIS, microwave radiometer and radiosonde TPW for 13 April 2001. Figure 5 shows the comparison of MODIS and microwave radiometer TPW for 08 May 2001. These initial comparisons show that the MODIS TPW is wetter than the microwave radiometer water vapor observations. MODIS forward model calculations and further TPW algorithm validation using Cart Site matchup data will be continued; probable causes for the bias will be explored.

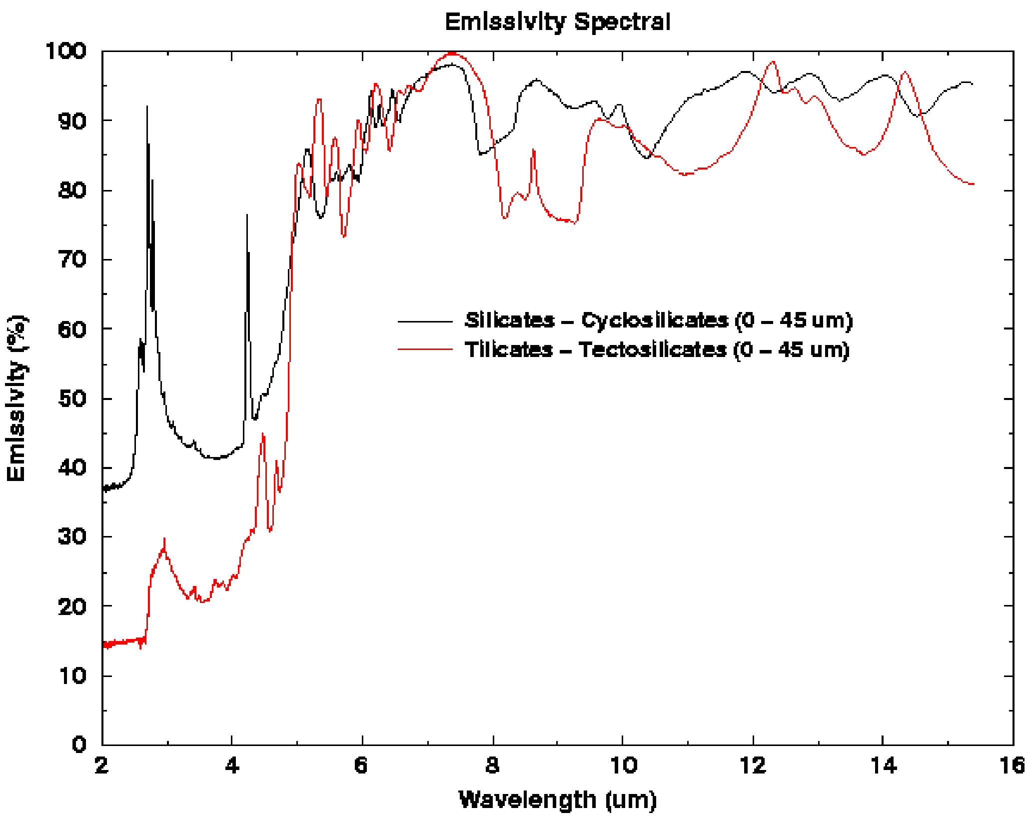


Figure 1: Emissivity spectral of silicates and tilicates.

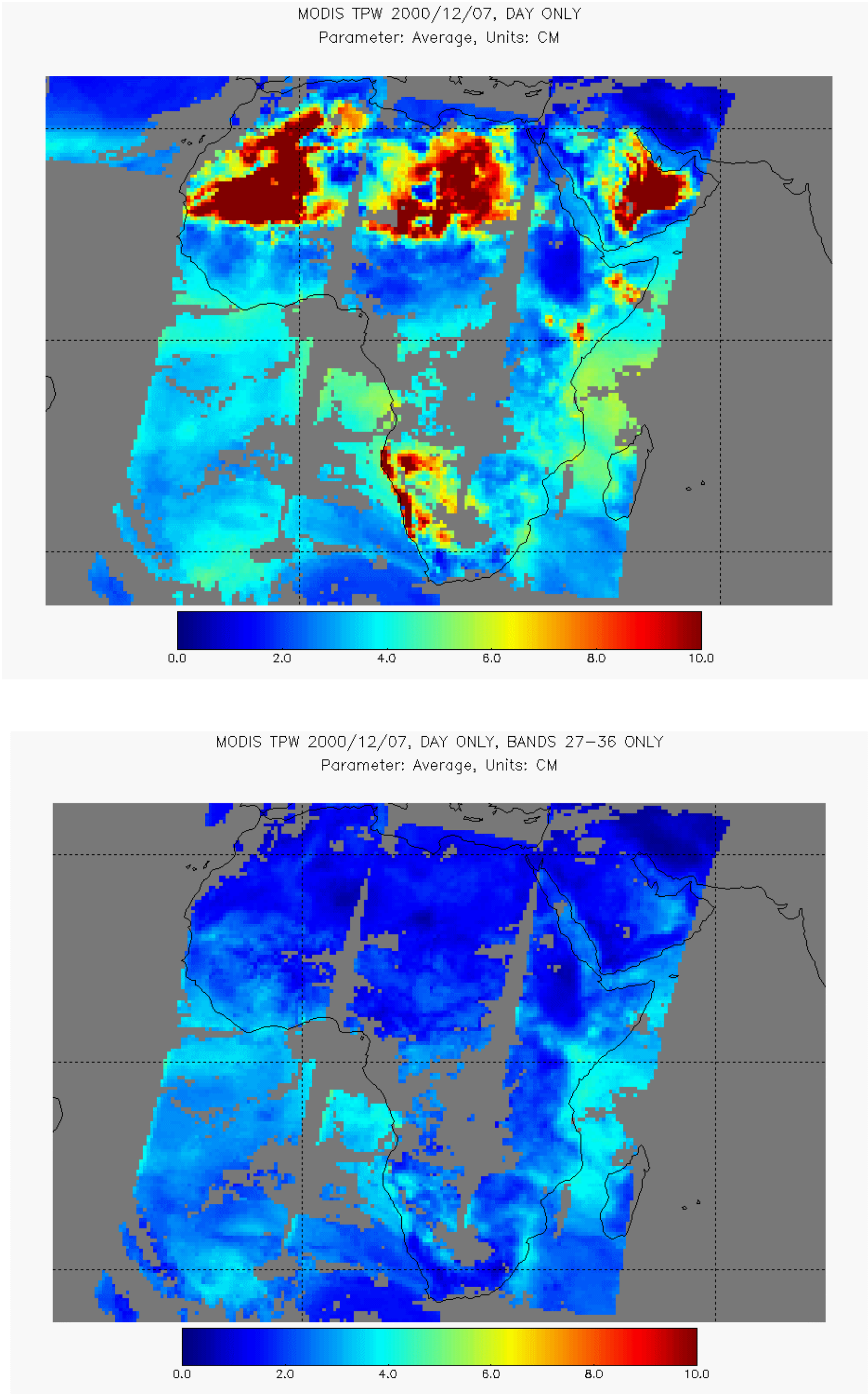
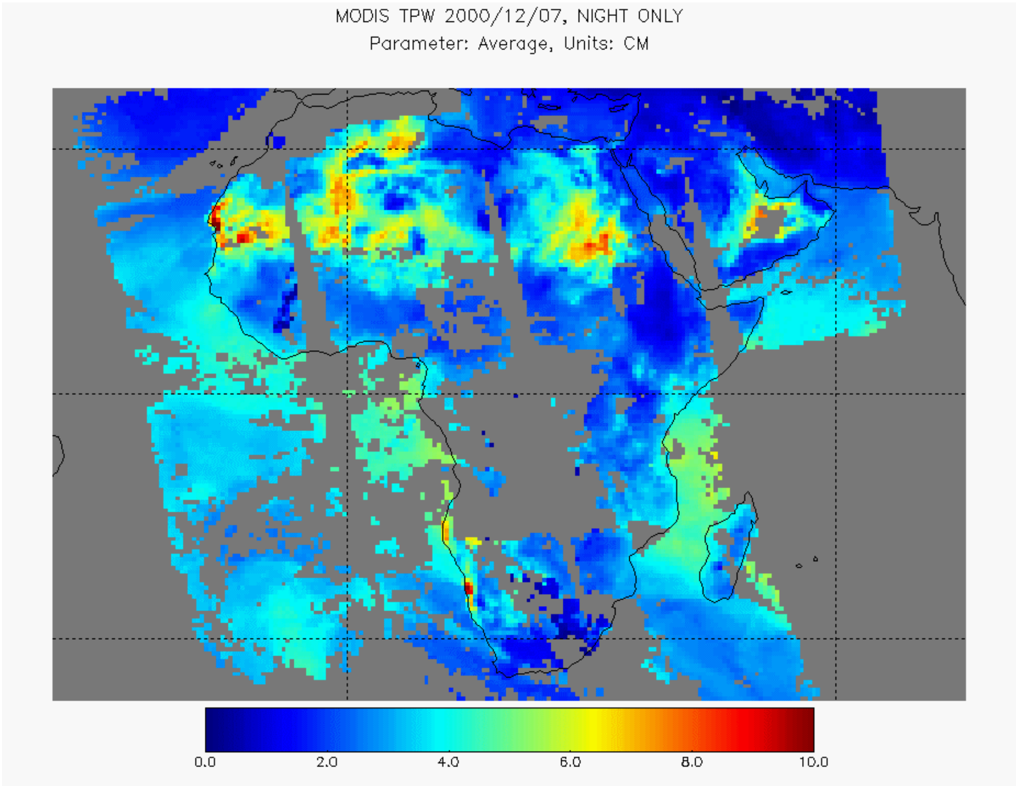


Figure 2: The daytime TPW images of 07 December 2000 from MODIS with the current algorithm (upper panel, bands 24 and 25 are included) and the updated algorithm (lower panel, bands 24 and 25 are not included) in the South African.



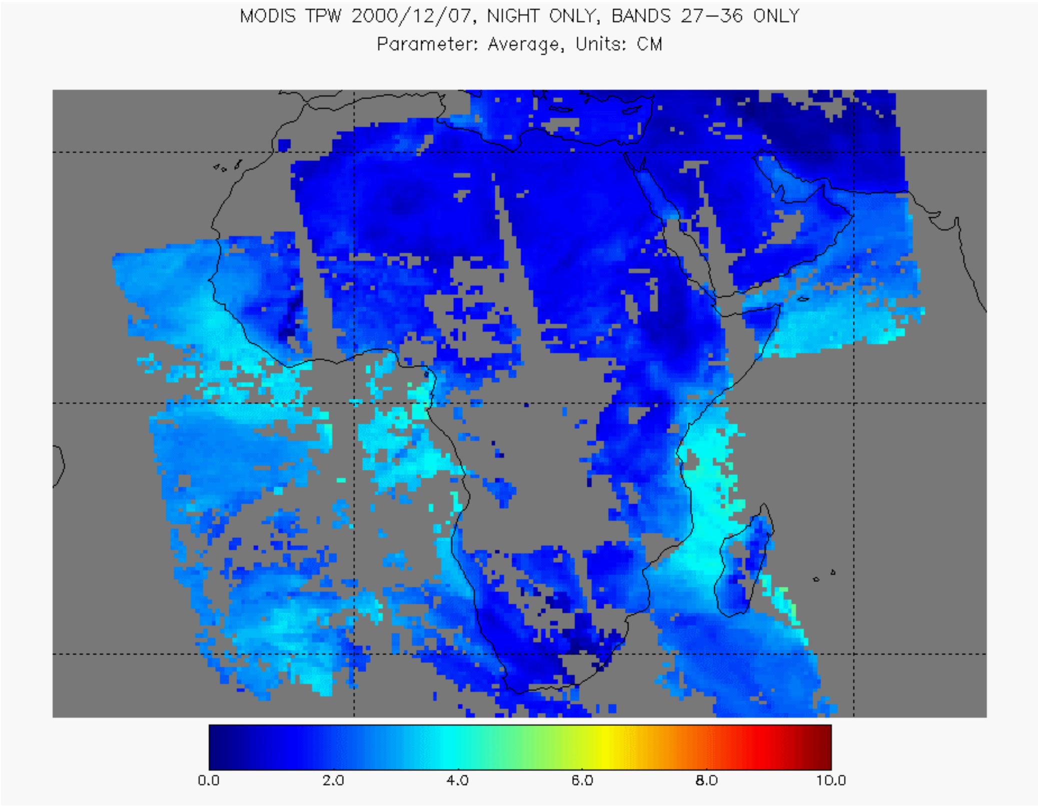


Figure 3: The nighttime TPW images of 07 December 2000 from MODIS with the current algorithm (upper panel, bands 24 and 25 are included) and the updated algorithm (lower panel, bands 24 and 25 are not included) in the South African.

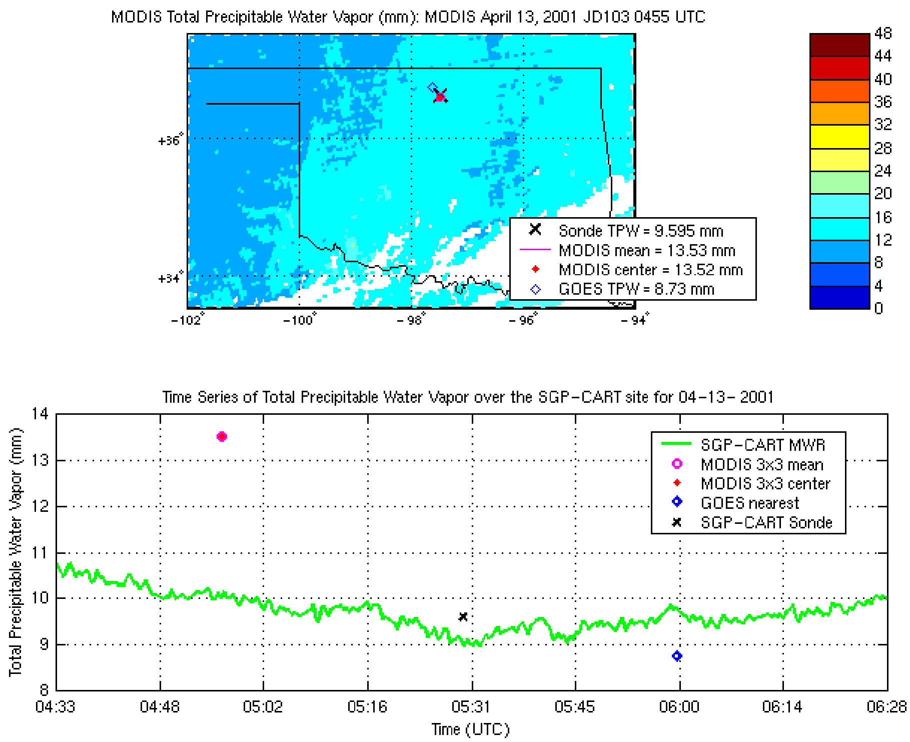


Figure 4: Comparison of TPW derived from MODIS 13 April 2001 and the radiosonde observation, as well as the microwave radiometer water vapor observations.

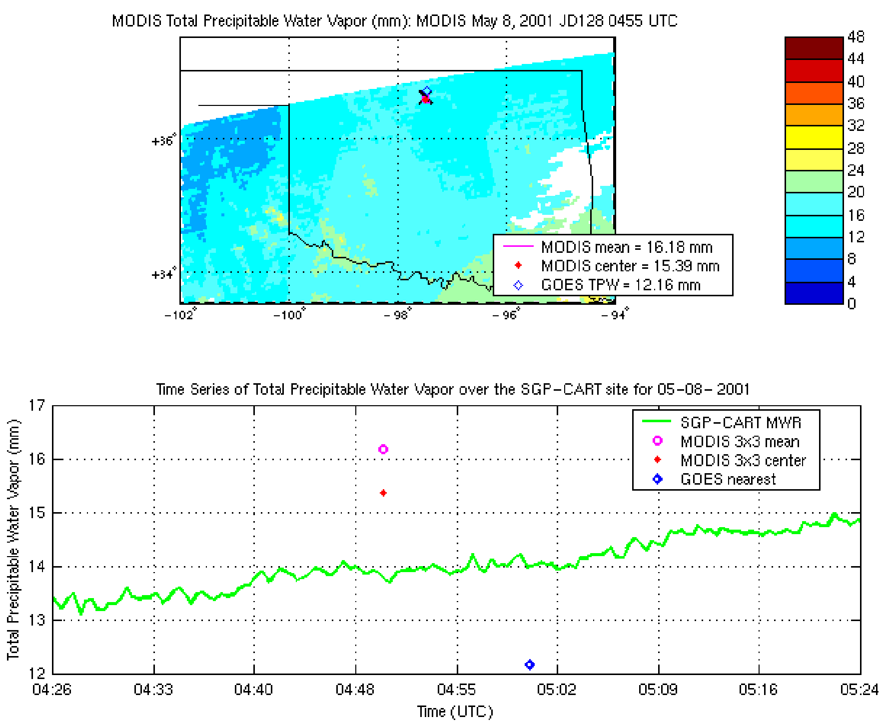
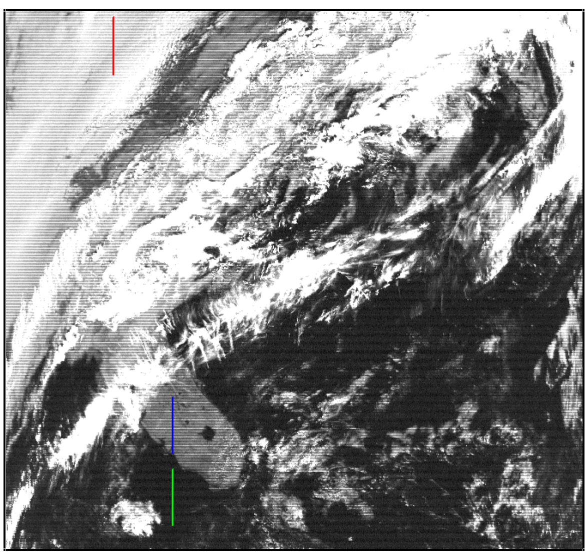


Figure 5: Comparison of TPW derived from MODIS 08 May 2001 and the Microwave radiometer water vapor observations.

MODIS Infrared Calibration and Evaluation of On-Orbit Performance

Striping in MODIS band 26 (1.38 µm) has causing the MODIS Cloud Mask to indicate clouds in clear land scenes. The reflectance in the striped lines (elevated signal) of clear land scenes exceeds the cirrus detection test threshold, causing striping in the Cloud Mask. The magnitude of the striping in band 26 data from clear ocean, clear land (Florida), and uniform stratus cloud has been reviewed (Figure 6). Striping is effectively non-existent for low signal, clear ocean data. However, it quickly elevates for the land and stratus cloud scenes. In Figure 6, the amplitude of striping (valley to peak) over land scenes is near 10% of band 26 L_{typ} and 10 – 15% of L_{typ} for stratus cloud scenes. Since the cirrus cloud signal is 5% or less of band 26 L_{typ}, the striping is often falsely interpreted as a cirrus cloud signal. The causes and behavior of the striping in band 26 are not well understood. Investigation of the band 26 calibration using the Solar Diffuser does not indicate any large non-linearities. Influence from other bands through residual electronic cross-talk has also been reviewed using on-orbit views of the SRCA; however, these don't seem to explain the large amplitude of the striping. Recently, the focus has turned to possible out-of-band influence from band 5 as a possible mechanism causing striping. An empirical approach for removing the striping is under consideration. However, the apparent signal dependence of the band 26 striping eliminates the use of simple offset corrections. Investigations continue, with the current emphasis being to identify relationships between MODIS band 5 and band 26 signals (see following paragraph).



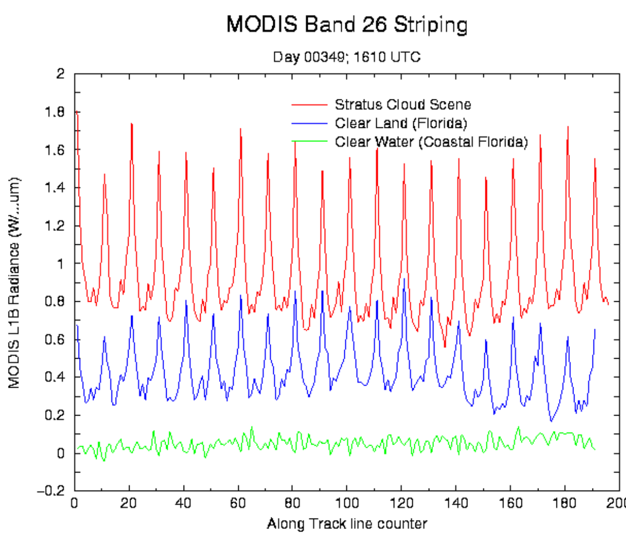


Figure 6: MODIS band 26 (1.38µm) along track radiance profiles for three scene types. Striping appears to be non-existant over the clear ocean scenes south of Florida, while it quickly amplifies in the higher signal levels associated with land and cloud scenes. Striping is also evident in ocean scenes with sunglint (not shown). The 10-15% amplitude of striping is causing the MODIS Cloud Mask to determine false cloud in clear land scenes.

MODIS band 26 (1.38µm) data shows surface features that are unexpected since atmospheric water vapor attenuates surface reflectances. Prelaunch test data suggests that band 26 may be influenced by out-of-band signals from band 5. Band 5 is sensitive to reflections from land surfaces, so a small component of band 5 signal is capable of significant influence on the typical low signal in band 26. To remove the band 5 influence from the band 26 data, a simple linear approach is being tested to subtract a band 5-dependent radiance component from the band 26 L1B radiance. Several correction coefficients (0.01 to 0.03) have been tested with encouraging early results (Figure 7). Surface features in moist atmospheric conditions can indeed be largely removed from the band 26 data by this procedure. In dry atmospheres, the surface signal in band 26 is reduced but not eliminated, but this is consistent with the physics of absorption in band 26, where roughly 1.0 cm of precipitable water in the atmospheric column is necessary to obscure surface features. In Figure 7, the land/water interface along the Gulf coast is removed after correction while surface features of the Midwest remain in the cool, dry atmospheric conditions behind a cold front. Testing other MODIS data granules has produced consistently favorable results; further testing for other surface types is necessary. While this band 26 correction for band 5 influences is not expected to greatly improve band 26 cirrus detection in dry atmospheric conditions (i.e. high elevation, high latitude regions), it shows great promise for improving thin cirrus detection over land surfaces (and sunglint regions) in moist atmospheric conditions. Additionally, this correction will be tested using detector dependent correction coefficients (based on band 5 radiances) and may provide a useful (and possibly physical) technique for removing striping in band 26.

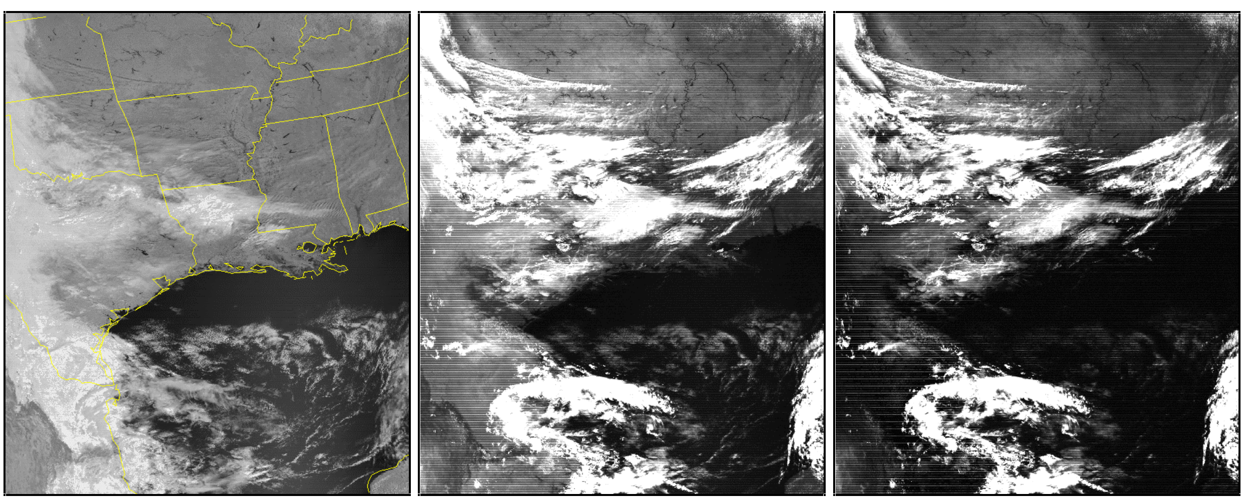


Figure 7: Demonstration of possible MODIS band 5 (1.2µm) out-of-band influence on band 26. Because of strong atmospheric water vapor absorption, forward model calculations indicate that band 26 should not see surface features, except in dry atmospheres. The relatively bright surface reflectance of band 5 (left) may be anomolously leaking into band 26 (center), causing the appearance of surface features like the land/water interface at the Gulf Coast. Subtracting 1.5% of band 5 radiance from band 26 (right) removes surface reflectance in the moist air mass along the Gulf Coast, but appropriately leaves surface reflectance in the dry atmospheric conditions of the Midwest (north of the broad cloud band defining a cold front boundary). A detector by detector based correction is also under investigation as a method to soften striping in the band 26 imagery as well.

MODIS band 34 (13.6 µm) striping is affecting the cloud products. The amplitude of the striping is about 0.75°C; it occurs in both the along track and across track directions and appears to contains a random element (possibly suggesting that 1/f detector noise is influencing this band). SBRS believes it is possible that 1/f noise may be greater in this band; the noise increased after a MODIS outgas procedure in August 2000. Data sets prior to August 2000 will be interrogated for their striping characteristics. In addition, since MODIS has recently returned to science mode using the power supply #1 and the A-side electronics, current band 34 performance will be checked for possible further insight into the striping. A destriping technique using wavelet theory shows some promise for significantly reducing the striping in band 34; further testing is planned.

MODIS L1B thermal IR band calibration is also being evaluated with data from ER-2 aircraft flying under MODIS. The University of Wisconsin has been involved in three campaigns (WISC-T2000, SAFARI-2000, TX-2001) where MODIS data has been available. The ER-2 has the MAS and SHIS instruments taking data over clear sky water scenes during each of these campaigns. The MAS data from these scenes is used in direct comparisons to the co-located MODIS data. The SHIS calibration (0.5°C or better accuracy) is transferred to MAS to improve the MAS radiometric accuracy. Viewing geometry, spatial resolution, and spectral dependencies are removed to isolate the MODIS radiometric accuracy. Additionally, the ER-2 has underflown MODIS at various scan mirror angles for insight into scan mirror angle influence on the MODIS calibration. The early results (Figure 8) with two days of TX-2001 data indicate that MODIS thermal bands are performing well, but not optimally for the clear sky Gulf of Mexico scenes sampled. The MODIS MWIR window bands appear to be close to the 0.75 – 1.0 % radiometric accuracy specification for the uniform warm, low reflectance scenes assessed. This suggests that electronic crosstalk in MODIS SWIR and MWIR bands is small for such scenes. The MODIS LWIR window bands at 11µm and 12 µm show cold residuals of about -0.5°C to -0.6°C, larger than the 0.5% radiometric accuracy specification. These findings are similar to MODIS residuals using the SAFARI-2000 data set (not shown). However given that the uncertainties are 0.5°C for the window bands and 1°C for the atmospheric bands, it is not possible to definitively state whether these MODIS bands are or are not within specification. MODIS LWIR atmospheric CO_2 bands appear to perform near the 1% accuracy specification with the exception of bands 35 and 36, the upper troposphere CO_2 bands at 13.9 µm and 14.1 µm. These bands show progressively larger positive residuals (i.e. MODIS is warmer than expected) with wavelength. MODIS viewing geometry differences on the two days seem to suggest that scan mirror reflectance dependence on mirror angles may be influencing the MODIS L1B calibration for some bands, most notably the 8.6 µm and LWIR CO_2 bands. However this assessment is dependent upon the accuracy of the spectral correction (a function of atmospheric conditions), which will be further investigated in the coming months. It was surprising to find large MODIS residuals for several bands when the mirror angle to the earth scene closely matched that to the onboard blackbody. At this angle, scan mirror effects are minimized, which was expected to minimize MODIS residuals. Large residuals suggest possible uncertainty and/or unexplained nonlinearity in the onboard blackbody characterization.

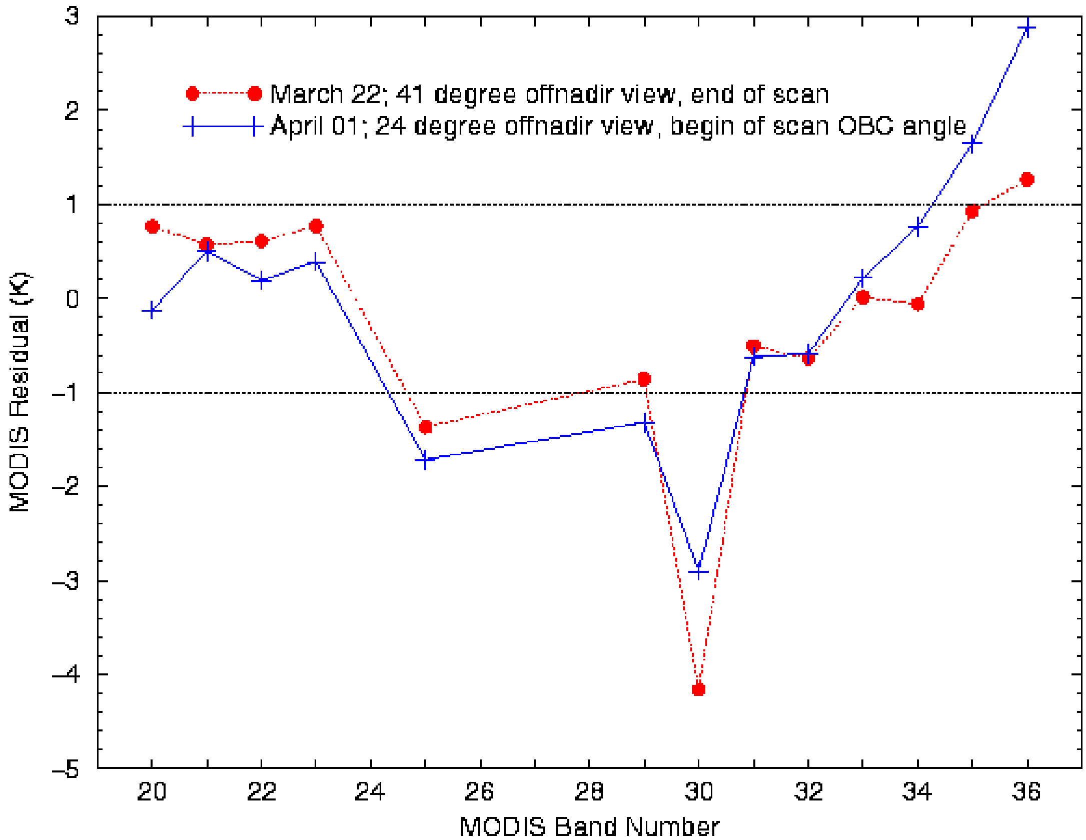


Figure 8: MODIS residuals after spectral correction. The April 01 viewing geometry was very similar to when MODIS views its onboard blackbody (angle of incidence, AOI=26.3°), minimizing scan mirror reflectance influence in those residuals. March 22 had a large scan mirror AOI near the end of the MODIS scan swath (i.e. potentially large scan mirror influence). The April 01 results suggest that MODIS LWIR window bands are cold by about 0.5°C (band 31, 32) to near 1°C (band 29). MWIR 4µm window bands (band 20-23) appear to be warm by up to 0.5°C. Upper troposphere CO_2 bands (25, 35, 36) show residuals exceeding 1°C; however, the large spectral correction of these bands increases the uncertainty of the residuals. Band 30 (ozone) residuals are large almost certainly because of inaccuracy in the chosen climatologically based ozone profile. Departures between March 22 and April 01 residuals are suggestive of scan mirror influence with the exception of the MWIR 4µm bands where sunglint is likely influencing the residuals of March 22. However, further analysis of the spectral corrections, especially for atmospheric bands, is necessary before drawing conclusions on scan mirror effects

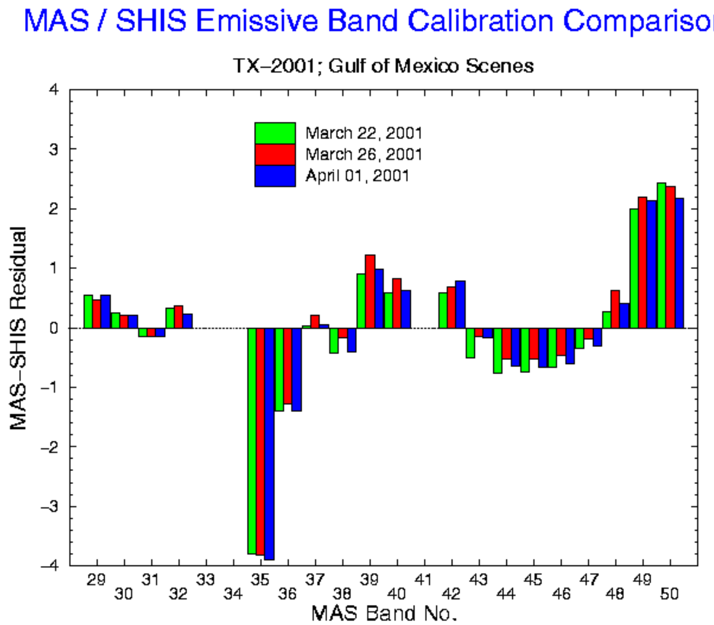
An important influence on the MODIS L1B accuracy assessment is the spectral correction, especially for atmospheric bands. The spectral correction accounts for spectral bandpass differences between MAS and MODIS and is a function of the atmospheric conditions (as represented by radiosonde data) used in a forward model. Imperfect representation of the atmospheric conditions by the radiosonde during the ER-2 and MODIS data collection can cause an error of 0.5°C or more in the spectral correction. The accuracy of the atmospheric characterization may be judged by the departure of the forward model top of atmosphere radiance from that observed by MAS (after calibration transfer from SHIS). The current forward model calculations agree closely with those of the MAS window bands (within a few tenths of a degree), however the atmospheric bands show departures of 1°C or more. Most offensive is the > 5°C departure between the forward model and MAS observations of the ozone band; this is a clear signal that the spectral correction for MODIS Band 30 needs further attention, probably in the ozone profile. For LWIR CO_2 bands, the 1°C departure also merits further testing. The atmospheric characterization and spectral correction for all MODIS atmospheric bands will be investigated further in the next quarter. The reduction of departures between the forward model and MAS radiances down to within 0.5°C is the goal and new MODIS residuals will be calculated using the updated spectral correction.

MAS IR Calibration Studies

MAS thermal IR data from the TX-2001 data set has been compared to that of SHIS to evaluate MAS calibration accuracy during the experiment. These comparisons have become an important method for tracking MAS calibration performance both for the short term (i.e. during an experiment) and the long term (one year or more). Trends in the comparisons suggest degradation of the various instrument components, while out-of-family results suggest characterization errors. MAS radiometric performance is used to evaluate MODIS radiometric accuracy; in that process, SHIS calibration is transferred to MAS via co-located data.

MAS and SHIS data have been compared for 22, 26 March and 01 April 2001 from TX-2001. For the comparisons of 26 March and 01 April the SHIS instrument was operated in a scanning mode, allowing an investigation into MAS off-nadir performance. The SHIS gold-coated mirror effectively minimizes scan angle influence while the MAS overcoated aluminum mirror is polarization sensitive. At nadir, the comparisons exhibit agreement on the three days (Figure 9) suggesting stable MAS and SHIS performance during TX-2001. Small changes (< 0.5°C) in the residuals from day to day are not considered indicative of performance change. The residuals vary from band to band, generally within +/- 0.5°C for window bands and within 1°C for atmospheric bands with the exception of MAS CO_2 sensitive bands 35, 49, and 50. These bands are susceptible to spectral characterization error and also require extrapolation of the calibration responsivity to very cold scene temperatures. While the MAS blackbody reflectance was carefully measured in January 2001, the extrapolation to cold scene temperatures makes MAS CO_2 bands sensitive to blackbody characterization error.

Scan angle dependence of MAS LWIR calibration was evaluated by comparing MAS – SHIS residuals for different scan mirror angles in the cross track direction. The results (Figure 10) suggest that most MAS LWIR bands exhibit similar small (tenths of a degree) scan mirror angle dependence. The effect is however noticeably different in the MAS 8.6 µm band (42), where there is evidence of a cross track shape difference to the MAS-SHIS residuals with a general movement towards more negativity near the limbs (i.e. MAS temperatures are depressed at the limbs compared to SHIS). This effect may be due to polarization effects as the MAS scan mirror orientation changes in its scan pattern. Such effects are known to exist in the mirror coatings used on MAS. Close attention will be paid to this behavior in future data set analysis. The 0.5°C apparent scan angle dependence of band 42 is an important characteristic that must be included when considering MAS-MODIS comparisons.



MAS Band	Central Wavelength
29W	3.64
30W	3.77
31W	3.94
32W	4.10
33C	4.21
34C	4.36
35C	4.55
36W	4.70
37W	4.86
38H	5.00
39H	5.15
40H	5.29
41H	5.38
42W	8.54
43O	9.68
44W	10.46
45W	10.95
46W	11.95
47H	12.81
48C	13.19
49C	13.73
50C	14.18

Figure 9: MAS-SHIS calibrated brightness temperature comparisons based on clear scenes of the Gulf of Mexico collected on three days during the TX-2001 field experiment. Over 100 SHIS observations per band were co-located with MAS to produce the residuals. MAS spectral band information given at right (W = Window, H = H_2O; C = CO_2; O = O_3). Most MAS window bands have residuals within about +/- 0.5°C, and show consistency from flight to flight suggesting stable performance of MAS during the experiment. MAS atmospheric band residuals for band 35, 49 and 50 are large, suggesting possible laboratory spectral characterization error of these bands. Atmospheric band residuals also are nearly constant for the three days sampled, suggesting spectrally stable performance of the MAS bands. Bands 33 and 34 not shown because spectral characterization is incomplete; no data collected for band 41 during TX-2001.

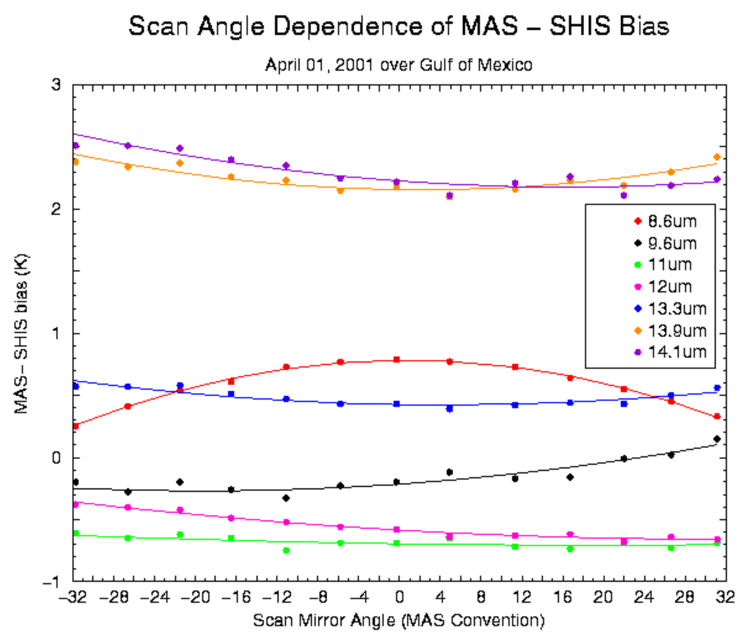


Figure 10: MAS-SHIS residuals as a function of scan angle for the LWIR spectral region. See Figure 9 for spectral band numbers. Most bands display some dependence on the MAS cross track scan mirror angle, which may be due to MAS scan mirror polarization sensitivity. The 8.6µm band (42) dependence stands apart from other bands with a large negative influence moving from nadir to limb across the scan swath.

ER-2 Field Experiment Activities

The Terra eXperiment – 2001 (TX-2001) was conducted out of San Antonio, TX from 14 March to 05 April 2001. A NASA ER-2 aircraft with MAS and SHIS instruments underflew Terra on seven missions (Table 1). Four MODIS calibration assessment missions (22, 26 March, 01, 04 April) were flown, primarily over clear sky Gulf of Mexico scenes. One mission was flown to monitor coastal zone sediment patterns (21 March) and their motions along Louisiana's sediment rich Atchafalaya Bay region. A mission on 31 March was flown to map atmospheric moisture in the immediate wake of a cold frontal passage over the ARM SGP CART site. An early mission (19 March) underflew Terra in partly cloudy skies. Analysis of the MAS and SHIS data sets is already underway to provide important insight into MODIS L1B calibration accuracy after one year of data collection. Scan mirror angle effects are being investigated in the MODIS calibration assessment; MODIS was underflown at the scan angles of –24°, -19°, 0° (nadir), 23°, and 33° over the Gulf of Mexico. The 01 April mission was conducted at the special scan angle of –24°, which is equivalent to the angle when MODIS views its onboard blackbody (i.e. removing scan mirror reflectance influence); these data will provide insight on MODIS onboard blackbody characterization. The 21 March coastal sediment mission, which included in situ water quality measurements, will be used to map and estimate coastal in-water sediments during the spring high-discharge season. The MAS and MODIS 21 March data set will also be used to transfer sediment concentration estimation to the MODIS platform. The moisture mission of 31 March included three overflights of the ARM SGP Central Facility, once with MODIS directly overhead. This data set will be used to map moisture gradients in the region of the ground-based network at the Central Facility. Comparisons of ARM SGP moisture data with the MODIS water vapor product will be investigated. ER-2 mission summaries, flight patterns and MAS quicklooks have been staged at the TX-2001 web page (http://deluge.ssec.wisc.edu/~shaima/).

A flight request for 24 ER-2 science flight hours has been submitted to NASA Airborne Sciences for FY02. The 24 science flight hours are directed towards underflights of MODIS on Aqua and Terra for the purpose of assessing L1B calibration and MODIS cloud and atmospheric water vapor products. The flights are requested in spring 2002 pending successful launch of Aqua. A deployment (CLAP-2002) in the southern USA is being planned and coordinated with the CPL instrument team at GSFC to combine MODIS and GLAS validation efforts. The CPL (lidar) provides cloud height and particle phase validation as well as optical depth estimation to the MODIS cloud product validation effort. Flights over the ARM SGP CART site and the Gulf of Mexico are anticipated.

Table 1. TX-2001 Deployment At a Glance

March 14 – April 05, 2001

Date	Flt#	Sensor	Region	Comments
3/14				ER-2 ferry from DFRC cancelled for TX weather.
3/15	049	M	CA to TX	***Ferry flight***. Clear skies over AZ, NM, TX. Vegetated. Upload S-HIS on ER-2. Sunny, dry, seasonal day in SAT.
3/16	050	SM	Gulf Mex.	***Checkout mission***.
3/17				Terra underflight cancelled by cloud cover at target.
3/18				Hard down day. Rainy cool day in SAT. MODIS Cal mission scheduled for tomorrow.
3/19	051	SM	Gulf Mex.	***MAS checkout mission***. Low clouds. Terra at 1707 UTC (21° scan angle). Limited clear water.
3/20				Down day for instrument work; post frontal along LA coast.
3/21	052	SM	LA coast	***MODIS Sediment mission*** over Atch. Bay. LSU in situ. Terra at 1655 UTC (-19° scan angle). 36 hrs post frontal. SHIS fail.
3/22	053	SM	Gulf Mex./LA	***MODIS Calibration mission*** over Gulf of Mexico and ***USGS photo mission***. Terra at 1737 UTC (33° scan angle).
3/23				LA Photo mission cancelled by clouds.
3/24				Down day. FROPA early in OK.
3/25				Down day. FROPA early through LA coast.
3/26	054	SM	Gulf Mex./LA	***MODIS Calibration mission*** over Gulf of Mexico and ***USGS photo mission***. Terra at 1713 UTC (0° scan angle).
3/27				Down day. Clouds and rain over SGP and LA coast.
3/28				Down day. Clouds and rain persist over SGP and LA.
3/29				Evening flight cancelled by clouds at SGP.
3/30				Gulf flight cancelled.
3/31	055	SM	CART	***MODIS Moisture Mapping mission***. Terra at 1729 UTC (-11° scan angle); 6 hrs post-frontal at ARM Central Facility.
4/01	056	SM	Gulf Mex./LA	***MODIS Calibration*** and ***USGS photo mission***. Terra at 1635 UTC (-24° scan angle). Post frontal airmass, light winds.
4/02				OK/KS and Gulf flight cancelled. Warm moist airmass taking hold in Plains and Gulf coast.
4/03				ER-2 down day. Warm, moist cloudy in southern Great Plains
4/04	057	SM	Gulf Mex.	***MODIS Calibration mission***. Terra at 1706 UTC (23° scan angle). Pre-frontal moist airmass. Popcorn cumulus and some clear scenes.
4/05	058	SM	Ferry	Overflight of clear water over Lake Tahoe

Sensor Legend: M = MAS; S = SHIS

MODIS Direct Broadcast Operations

As of 30 June, approximately 1200 Terra MODIS passes have been acquired and archived at SSEC. Since January 2001, the MODIS data have been routinely and automatically processed to Level-1B using the International MODIS/AIRS Processing Package (IMAPP) and the latest 7 days of MODIS passes have been made available online. In addition, a quicklook website has been established to allow regional and continental images from MODIS to be distributed within 90 minutes of the end of each pass (See Figures 11 and 12).

The FTP site for the Level-1B data is:
ftp://terra.ssec.wisc.edu/pub/terra/modis

The Web site for the quicklook images is:
http://terra.ssec.wisc.edu/terra/

Several high impact color images created from MODIS data acquired at SSEC have been featured at the NASA Earth Observatory. See the links below for examples.

Snowcover in the US Midwest, January 2, 2001:
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4549

Nor'Easter, March 4, 2001:
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4710

Mississippi River Sediment Plume, March 5, 2001:
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4720

Spring Floods on the Mississippi, April 18, 2001:
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4804

Gulf Stream's Brightness Temperature, May 2, 2001:
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4818

Since May, direct broadcast MODIS data acquired by SSEC over Lake Tahoe have been routinely and automatically pushed to Simon Hook at JPL, who is conducting an EOS Validation Investigation. Hook is comparing the MODIS observations to downward looking surface radiometer measurements. SSEC worked with Hook to implement customized extraction of MODIS Level-1B data in all 1000 meter resolution bands over four distinct sites on Lake Tahoe, as well as extracting data over the entire Lake. This process now runs entirely automatically and sends data to Hook every time Terra MODIS sees Lake Tahoe.

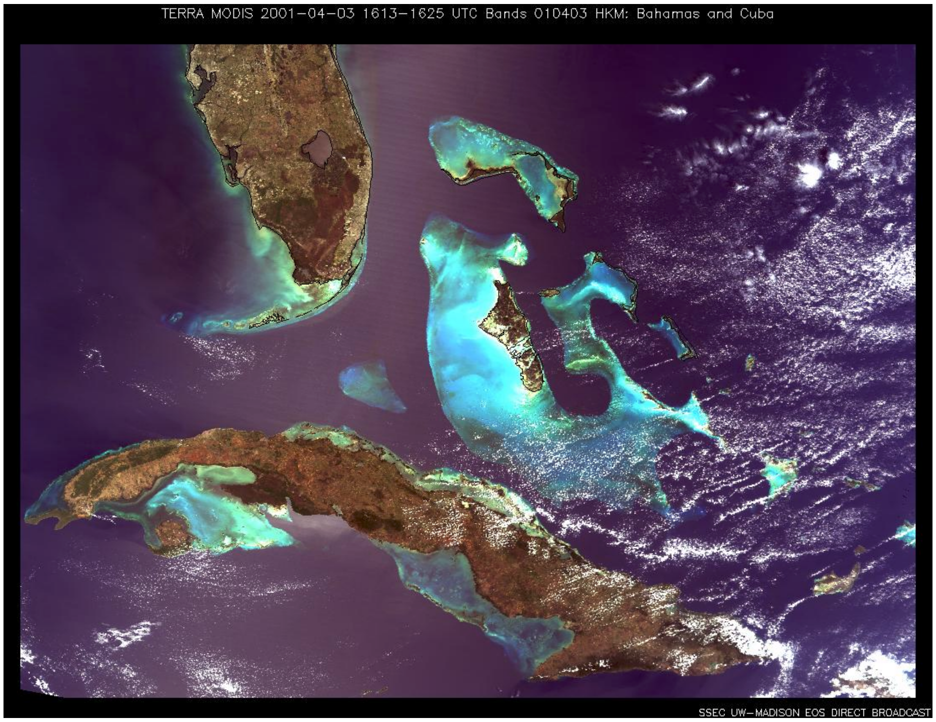


Figure 11: True Color image of the Bahamas and Cuba acquired via direct broadcast at SSEC, UW-Madison on April 3, 2001.

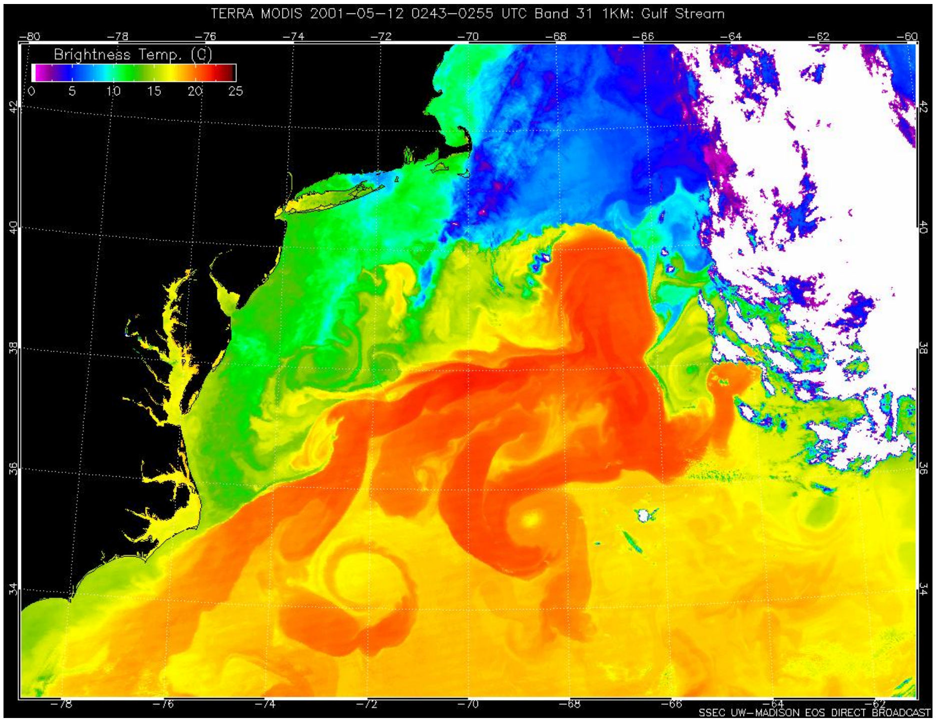


Figure 12: False color infrared image of the Gulf Stream acquired via direct broadcast at SSEC, UW-Madison on May 12, 2001.

MODIS Direct Broadcast Software

Version 1.2 of the International MODIS/AIRS Processing Package was released on 13 April 2001. This second major update for Terra MODIS included the following:

- Calibration algorithm and lookup tables are updated to versions 2.5.5 and 2.5.5.1 respectively, which includes calibration data for the B-side electronics on MODIS (the switch to B-side electronics occurred on 1 November 2000). The calibration in IMAPP v1.2 is date dependent, and may be used for all Terra MODIS data back to February 2000. This version also includes corrected software for aggregation of the 250 m and 500 m spectral bands to higher spatial resolution.

- Geolocation is significantly improved when using only the Level-0 platform ephemeris and attitude information (i.e. in near-realtime). Terrain correction is now available as an option (requires that DEM data files be installed). Definitive Terra ephemeris and attitude data are now available via FTP for input to IMAPP.

- The Level-1A algorithm is more resistant to Level-0 input file anomalies. Processing now terminates gracefully if a packet with an improper length is encountered in the Level-0 input file. IMAPP is available for download at:
- http://cimss.ssec.wisc.edu/~gumley/IMAPP/

In order to verify the IMAPP calibration for MODIS, Level-1B 1000 meter resolution radiance data for 11 April (day 70) from 1610 to 1615 UTC were acquired from the GSFC DAAC, and compared to the corresponding direct broadcast data acquired at SSEC. The GSFC data were processed with the operational calibration v2.5.5 on a SGI IRIX 6.5 platform using the native compiler. The SSEC direct broadcast data were processed with IMAPP v1.2 on a Solarisx86 platform using the gcc compiler. All valid pixels in each band were compared in radiance units. MODIS Level-1B radiances are stored as scaled 16-bit integers. Thus the smallest radiance difference that can be represented is the scale factor itself, which corresponds to one scaled integer. In the radiance comparison, pixels that differed by more than one scaled integer were considered 'different'. To allow for algorithm, platform, and compiler differences, pixels that differed by one scaled integer are considered to be effectively the same. In all bands, more than 99.96% of the valid pixels matched to *one scaled integer or better*.

The MODIS fire detection group has adopted IMAPP for the Rapid Response System at GSFC. MODIS Level 0 data are obtained through the NOAA MODIS Near Real Time Processing System at NASA/GSFC. They are processed to L1B data using the IMAPP software distributed by the University of Wisconsin. L1B data are then processed to L2 and L3 products using rapid response code specifically developed for this application. The fire detection group is committed to releasing the IMAPP-compatible fire algorithm to the direct broadcast community by the end of 2001.

MODIS Cloud Mask

An updated version of the MODIS cloud mask algorithm was delivered to SDST on 3 March 2001. The major changes were:

- Added elevation information. A high elevation flag is set when elevation is greater than 2000 meters.
- Turned off 1.38 um cloud test at high elevations (> 2000 meters).
- Fixed code bug in snow detection subroutine.
- Expanded list of arid ecosystems.
- Refined final clear-sky confidence confirmation test for arid regions including an elevation adjustment for the 11 micron brightness temperature threshold.
- Created separate subroutine and thresholds for cloud detection in Antarctica.
- Adjusted thresholds for snow detection.
- Adjusted thresholds for cloud detection over snow and ice-covered surfaces.

These changes resulted in significant improvements in clear vs. cloudy sky discrimination for snow-covered areas, high elevation regions, and semi-arid lands, particularly in those areas bordering the Sahara and Kalahari Deserts.

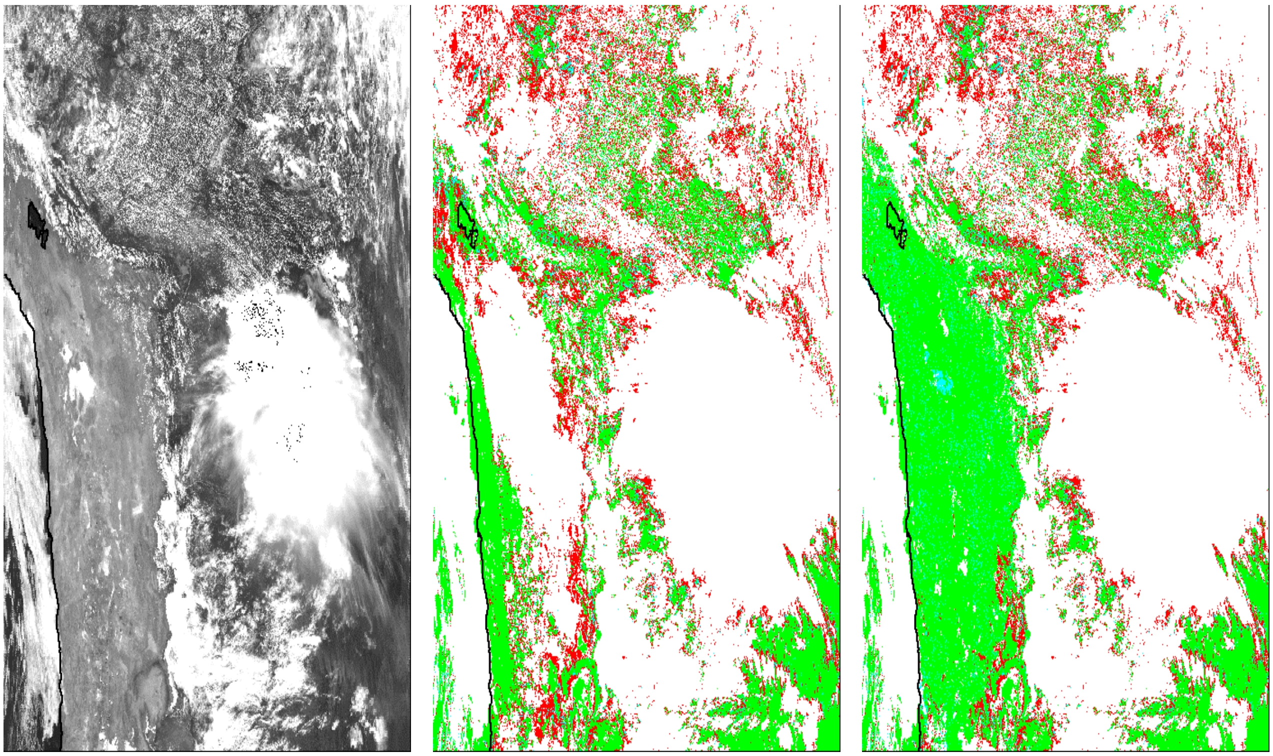
Figures 13, 14 and 15 show examples of the improvement in each of the three areas. Figure 13 shows a portion of South America with the Andes Mountains to the left of nadir. Many false clouds were reported in the original version (center) which are corrected in the updated cloud mask (right). Much of the improvement is due to discontinuing the use of the 1.38 μm cloud test in high elevations. Figure 14 shows a mountain snow scene from the Canadian Rocky Mountains in North America. Many more snow-covered areas are now properly indicated as clear. Figure 15 shows a scene in central Africa from about 15 north to 5 south latitude. The Sahel region just to the south of the Sahara Desert appears at the top of the images. Note the improvement in the updated mask (right). The Sahel region has been re-classified as an arid region within the cloud mask algorithm because of the relatively bright surfaces found there.

Efforts to further improve the cloud mask have continued since the March 2001 update. Several concerns from users, noted at the Terra Cloud Mask Workshop, are being addressed. Work has begun to reduce false clouds on coastlines, rivers, and inland lakes. The 250-meter cloud mask is being modified so that it will simply echo the 1-km results.

Terra Cloud Mask Workshop

A workshop to exchange information regarding cloud detection with instruments on Terra was held at the University of Wisconsin-Madison on 8-9 May 2001. All Terra instrument science teams were represented. Much of the discussion involved the MODIS cloud mask. Cloud issues included (1) consistency between night-time (IR only) and day-time cloud masks, (2) false cloud detection in high elevations and arid / semi-dry regions, (3) detecting thin cirrus with the 1.38 micron channel, (4) accounting for shadows, (5) distinguishing clouds from heavy dust and aerosols, (6) improving cloud masks along coastlines and cloud edges, (7) improving snow/ice versus cloud separation, and (8) reducing the effects of detector striping. Cloud mask intercomparisons between the various satellites on board the Terra spacecraft were initiated; logistics for selecting and sharing intercomparison data sets were defined. Validation of satellite cloud detection using ground instruments like lidar and radar were discussed. Progress during the summer will be reported at the next science team meeting.

MODIS Data from 14:40 UTC 5 November, 2000



MODIS 0.66 µm | Original Cloud Mask | Updated Cloud Mask

green = clear, cyan = probably clear, red = uncertain, white = cloudy

Figure 13: Scene from Andes Mountains showing false cloud reductions in high elevation regions.

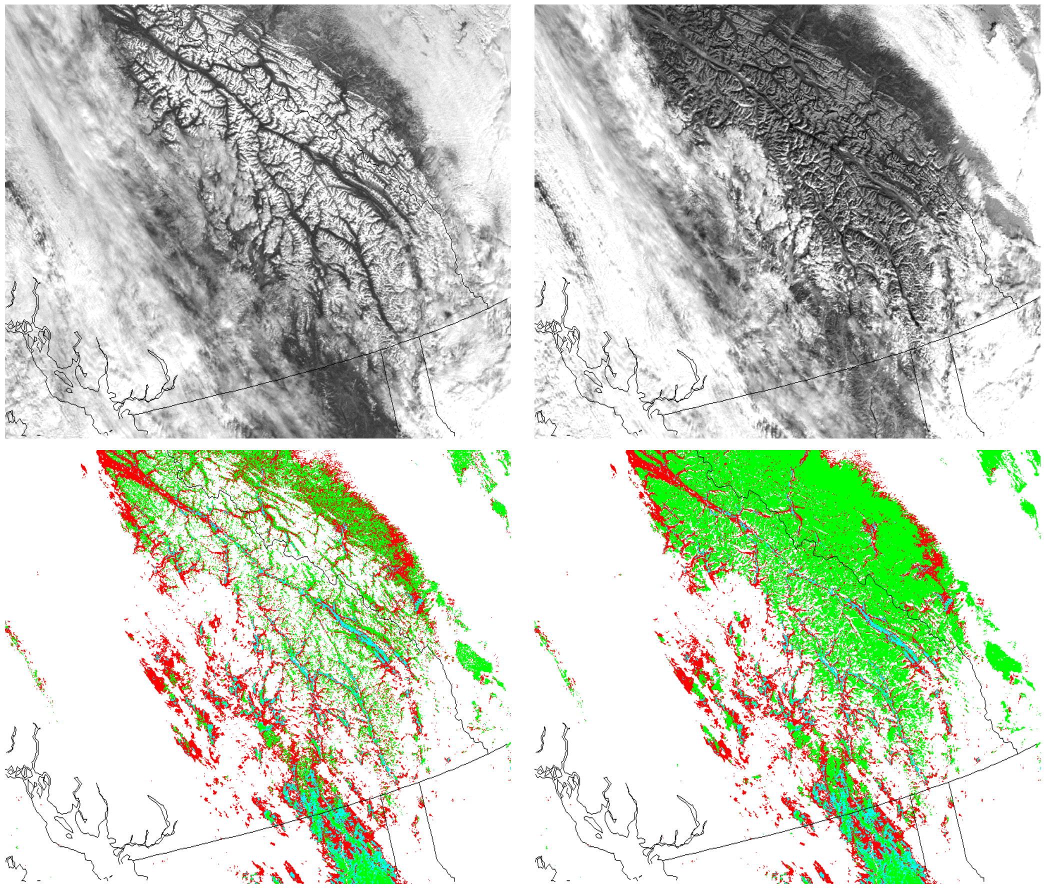
MODIS Data from 19:15 UTC 5 November, 2000

Left:
MODIS 0.66 µm

Right:
MODIS 1.6 µm

Left:
Original Mask

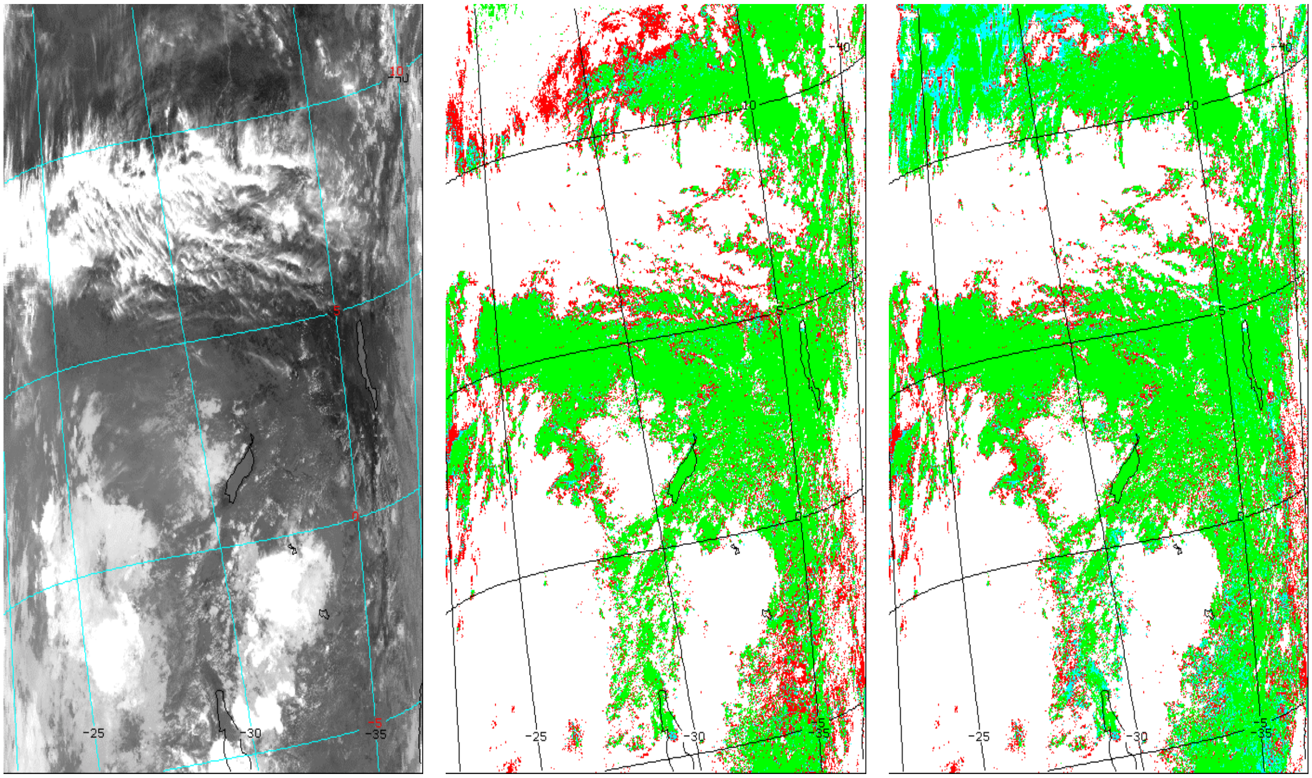
Right:
Updated Mask



green = clear, cyan = probably clear, red = uncertain, white = cloudy

Figure 14: Snow-covered scene from the Canadian Rocky Mountains showing reduction in false cloud retrievals.

MODIS Data from 08:40 UTC 8 December, 2000



MODIS 11 μm Original Cloud Mask Updated Cloud Mask

green = clear, cyan = probably clear, red = uncertain, white = cloudy

Figure 15: African scene showing improvements in semi-arid conditions.

<u>Cloud Phase</u>

Over the past six months, the MODIS IR cloud thermodynamic phase product has improved substantially and the operational software was upgraded to reflect these improvements. The original algorithm was based on IR bands at 8.5, 11, and 11 μm. The algorithm was quite complex. Based on analyses of global MODIS data, anomalies were found in the product and the causes were difficult to ascertain. To stabilize routine operational analyses, the best results were obtained with a simplified algorithm based solely on the 8.5 and 11 μm bands. The software is now quite dependable, it works on a pixel-by-pixel basis (instead of an array of data), and the anomalies are no longer present. The updated software has been implemented at the GSFC DAAC.

Investigation of merged cloud top temperature and cloud phase products began. These algorithms are run independently of each other and involve completely different analysis approaches. For both daytime and nighttime global results, the frequencies of co-occurrence between cloud top temperature and cloud phase were tracked. Figure 16 is an example from 05 November 2000 and shows the frequency of the time that a cloud has a cloud top temperature between 253K and 268K and is in a water phase (possibly areas of supercooled water clouds). This type of information is potentially of great interest to the field of aviation when aircraft icing is of concern. Note the prevalence of cold water clouds at high latitudes in both hemispheres.

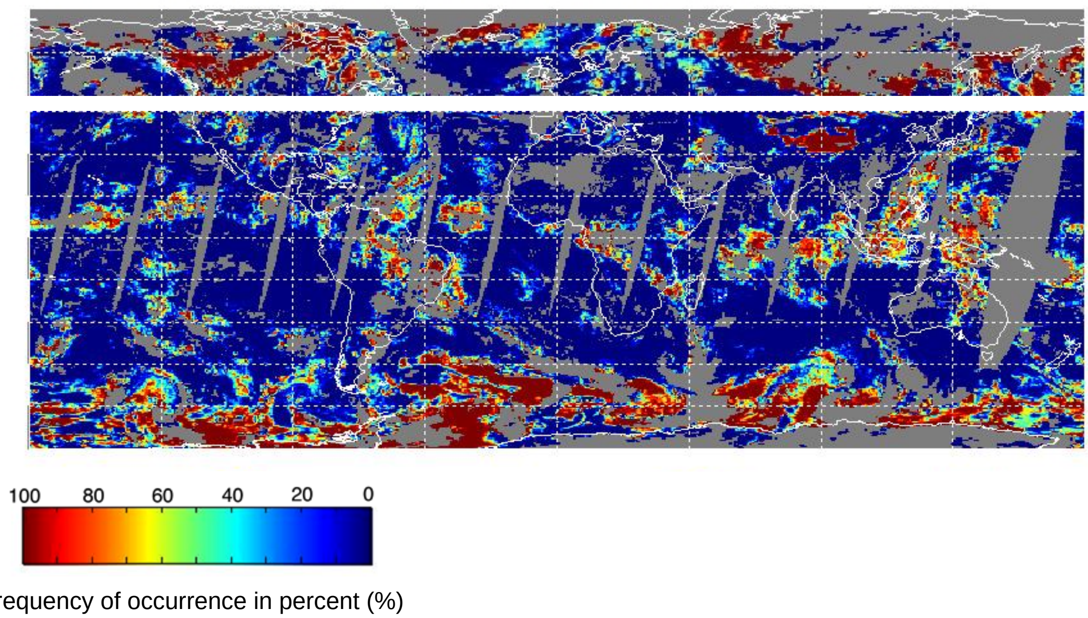


Figure 16: Frequency of the time that a cloud having a cloud top temperature between 253K and 268K is determined to have a water phase, 5 November, 2000 (daytime only).

DATA ANALYSIS

Cloud Top Properties

Through inspection of various Level 2 MODIS cloud products, it was discovered that MODIS cloud top pressures were sometimes grossly incorrect over low-level clouds. The cause was discovered to be (1) detector to detector striping in bands 33-36 and (2) high random noise especially in band 34 (13.6 µm). These problems cause clear minus cloud signals to be inappropriately large and lead to cloud heights which are too high (cloud top pressures too low). In order to mitigate the problem in the near term, minimum clear minus cloud thresholds in the cloud top properties code (MOD06CT) were raised significantly. Thus a "window channel" cloud height retrieval will be reported for most low-level clouds, which usually gives a reasonable value. A possible detriment is that some high, thin clouds may be incorrectly classified as thicker, mid-level or low-level clouds because the full CO_2-slicing algorithm is prevented from being performed. Efforts are underway to find methods of efficiently "de-striping" the CO_2 absorption channels (bands 33-36).

Polar Winds

Tropospheric winds play an important role in the energy and mass balances of the polar regions. Mid- and upper-level winds control the horizontal flow of heat and moisture to, from, and within the Arctic and Antarctic. However, no routine measurements of winds are made over the Arctic Ocean and most of the Antarctic continent. While geostationary satellites provide useful wind information in the low and midlatitudes, they are of little use at high latitudes due to poor spatial resolution.

Can polar orbiting satellites be used for wind estimation at high latitudes? The orbital characteristics that affect wind estimation from polar-orbiting satellites have been examined to assess limitations due to temporal sampling. Equatorward of 60 degrees latitude the temporal sampling of the Terra and future Aqua satellites is too sparse to obtain meaningful wind estimates Figure 17. However, poleward of about 75 degrees the coverage is such that useful wind information can be obtained throughout the course of a day.

Results of a case study for the Arctic are shown in Figure 18. The automated procedure that is currently used for geostationary satellite cloud-drift winds has been modified for use with MODIS, taking advantage of MODIS' high spatial resolution and its advanced capabilities for surface/cloud discrimination and cloud height determination. The figure only shows vectors derived by tracking clouds. Water vapor features have also been used and the combined wind vector set provides a high-density look at atmospheric motion. Ultimately, we expect that the assimilation of these satellite-derived wind estimates in coupled ice-atmosphere models will improve our ability to predict changes in the surface energy balance and ice mass.

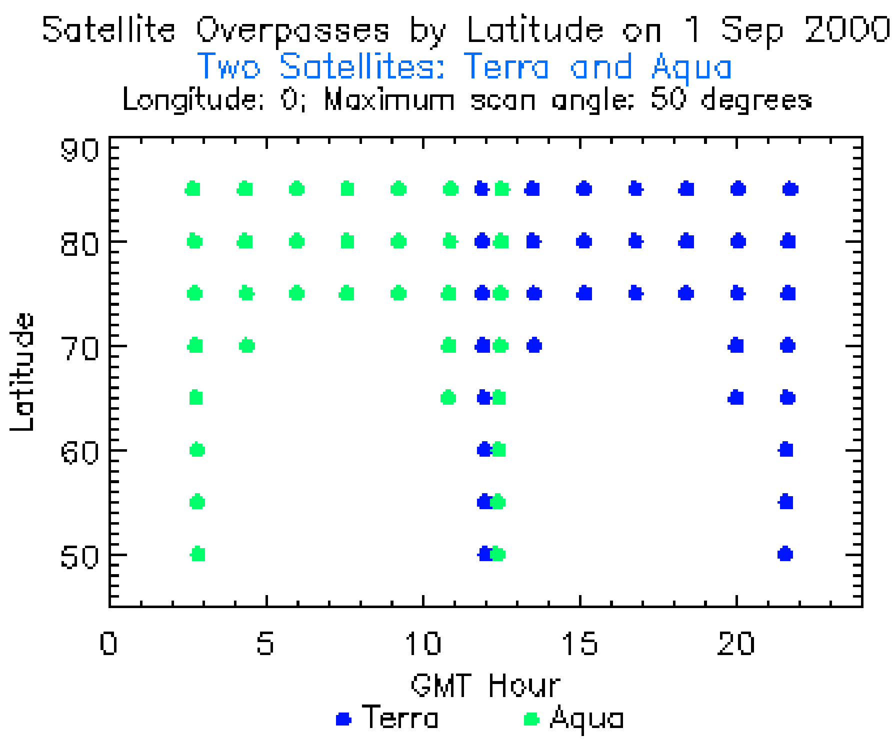


Figure 17: Overpasses of Terra and Aqua satellites as a function of latitude for a single longitude over the course of one day.

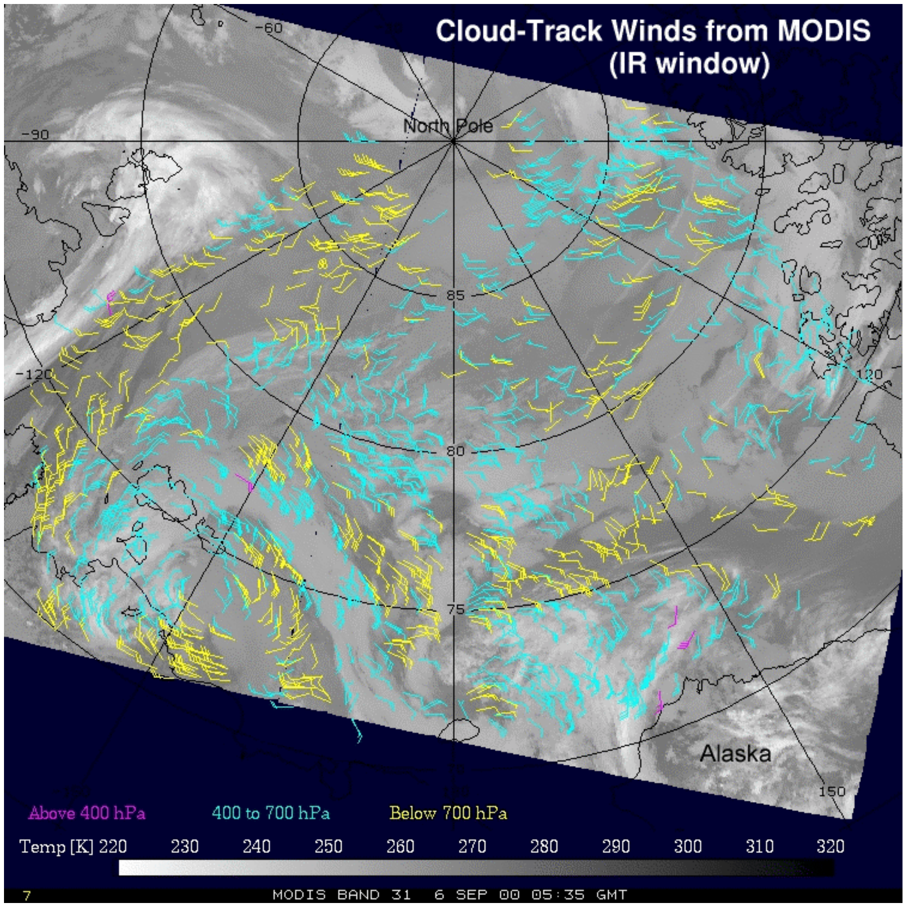


Figure 18: Cloud-track winds from MODIS for a case in the western Arctic. The wind vectors were derived from a sequence of three images, each separated by 100 minutes. They are plotted on the first 11 micron (band 31) image in the sequence.

Comparison of MODIS Infrared Observations to Calculations

Since March 2001, MODIS infrared observations over the ARM CART site in Oklahoma have been routinely and automatically extracted from the Level-1B data acquired by direct broadcast at SSEC. The observations are then compared to forward model calculations for the same location, time, and viewing geometry. This effort is helping to confirm and characterize systematic biases in the MODIS infrared bands.

The results from an analysis of nine clear-sky cases over the CART site are shown in Figure 19. Radiosonde temperature and mixing ratio profiles, radiosonde surface temperature, and a standard atmosphere ozone profile were used as input to a line-by-line algorithm (LBLRTM). GDAS temperature and mixing ratio profiles and a standard atmosphere ozone profile were used as input to a fast regression based algorithm. Clear-sky cases when MODIS passed over the CART site with viewing zenith angle < 50 degrees were used.

The comparisons depend greatly on the surface temperature used as input to the forward calculation. Considerable variation occurs between GDAS surface and GDAS ground temperatures (sometimes > 10 K), and this leads to significant differences in the Observed minus Calculated MODIS brightness temperatures (blue and green lines). Reasonable agreement exists between the LBLRTM runs (red lines) and the forward model runs (yellow lines) when the *same* (radiosonde) surface temperature is used for both.

SSEC will continue to collect and analyze direct broadcast MODIS observations over the CART site for radiance comparisons and also for product validation.

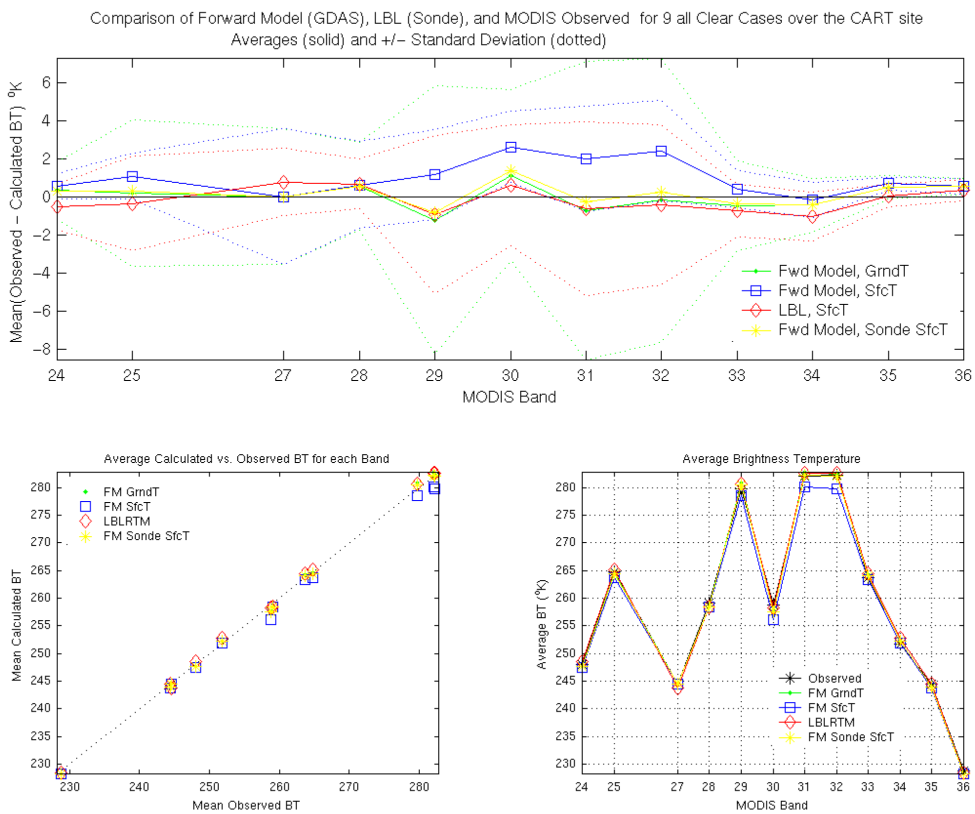


Figure 19: Average brightness temperature comparisons for 9 clear-sky cases over the CART site.

- LBLRTM (Red lines)
- Fast model with GDAS surface temperature "TMP:sfc" (Blue lines)
- Fast model with GDAS Ground temperature "TMP:0-10cm down" (Green lines)
- Fast model with radiosonde surface temperature (Yellow lines)

<u>CO_2 Slicing</u>

A modified CO_2 slicing algorithm was investigated wherein adjustments of both surface emissivity and cloud emissivity ratio are considered. CO_2 slicing has been generally accepted as a useful algorithm for determining cloud top pressure (CTP) and effective cloud amount (ECA) for tropospheric clouds above 600 hPa. To date, the technique has assumed that the surface emissivity is that of a blackbody in the long wavelength infrared radiances and that the cloud emissivities in spectrally close bands are approximately equal. In the modified CO2 slicing algorithm, surface emissivity is adjusted according to the surface types and the ratio of cloud emissivities in spectrally close bands is adjusted away from unity according to radiative transfer calculations. The new CO_2 slicing algorithm was examined with MAS CO_2 band radiance measurements over thin clouds and validated against Cloud Lidar System (CLS) measurements of the same clouds; it was also applied to GOES Sounder data to study the overall impact on cloud property determinations. For high thin clouds an improved product emerges, while for thick and opaque clouds there is little change. For very thin clouds, the bias of differences is about 10 to 20 hPa and RMS (root mean square bias) difference is approximately 50 hPa; for thin clouds, there is about 10 hPa bias and RMS difference is approximately 30 hPa. The new CO_2 slicing algorithm places the clouds lower in the troposphere.

Figure 20 shows a comparison of CLS and MAS cloud height determination over Kansas and Oklahoma in the central United States on 16 April 1996 between 22:02 and 22:16 UTC. There were numerous high thin clouds in evidence. Single layer cloud observations from the CLS and MAS cloud retrievals for five cloud emissivity ratios (0.95, 1.025, 1.0, 1.05, and 1.075) are shown; the same value is used for all CO2 spectral pair ratios. The distribution of cloud top height difference (CLS – MAS) is shown in 1000m intervals; at an altitude of 10 km in a U.S. standard atmosphere, 500 m corresponds to ~ 20 hPa. The best performance is found for a cloud emissivity ratio of 1.025, with about 60% of the comparisons within 500 m.

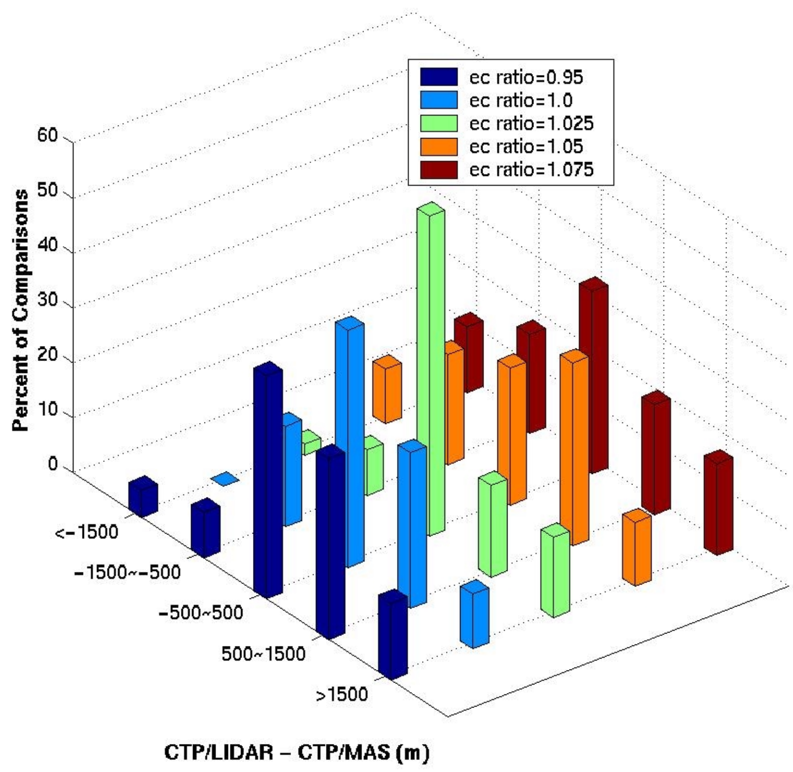


Figure 20: Comparisons of cloud top heights between from CLS and the MAS CO_2 slicing algorithm with different cloud emissivity ratio adjustments [0.95, 1.0 (no adjustment), 1.025, 1.05, and 1.075]. The MAS data is from single layer clouds and cloud top heights are greater than 4000 m on track 14 on April 16, 1996.

MEETINGS/CONFERENCES

Bryan Baum, Shaima Nasiri, and Ping Yang presented a paper entitled “Global and regional cloud properties derived from MODIS data” at the 11th ARM Science Team Meeting, Atlanta, Georgia, March 19-23, 2001.

Bryan Baum, Chris Moeller, Hong Zhang, Jeff Key, Jun Li, Liam Gumley, Shaima Nasiri, and Suzanne Wetzel attended the Terra Cloud Mask Conference at the University of Wisconsin-Madison, May 8-9, 2001.

Chris Moeller presented a talk on “MODIS L1B Validation for Thermal Bands” to the plenary at the MODIS Science Team meeting, Jan. 2001.

Chris Moeller attended the MAS Instrument Annual meeting on June 1, 2001 at GSFC and presented results of MAS and SHIS calibration comparisons as well as other MAS calibration considerations.

Jun Li presented a paper entitled “Atmospheric Retrievals from MODIS measurements: A Comparison with GOES sounder products” at the Optical Remote Sensing of the Atmosphere held February 5 –8, 2001 in Coeur d’Alene, Idaho.

Paul Menzel, Liam Gumley and Rich Frey attended the MODIS Science Team Meeting at NASA GSFC, January 23-25, 2001. Paul Menzel presented cloud properties gleaned from CO2 slicing (temperature, height, and amount) and tri-spectral (phase) algorithms in search of super cooled clouds.

Paul Menzel attended the Optical Society of America Topical Meeting on Optical Remote Sensing of the Atmosphere and presented an invited paper on “Remote Sensing of Land, Ocean, and Atmosphere with MODIS” held February 5 –8, 2001 in Coeur d’Alene, Idaho.

Paul Menzel visited the Cooperative Institute for Research in the Atmosphere (CIRA) and gave a presentation on “Remote Sensing of Land, Ocean, and Atmosphere with MODIS” to about thirty scientists on March 14, 2001. The talk included MODIS results from science team members on cloud detection, cloud property correlations between temperature and phase, sea surface temperature, chlorophyll, snow/ice cover, leaf area indices, and aerosol particle size.

Paul Menzel and Steve Ackerman chaired the Terra Cloud Mask Conference at the University of Wisconsin-Madison, May 8 – 9, 2001.

Paul Menzel presented a seminar on “Remote Sensing of Land, Ocean, and Atmosphere with MODIS” at the Finnish Meteorological Institute and the University of Helsinki in Helsinki, Finland on May 30, 2001. Examples of the many MODIS remote sensing firsts (250 meter resolution in the visible from leo, accurate visible cal with Spectro-radiometric Calibrator Assembly, tri-spectral 8.6, 11.0, 12.0 micron windows for cloud phase determination, 1.38 micron for thin cirrus detection, a fire channel with 500 K saturation, 1 km water vapor imagery) helped stimulate FMI to install a direct reception facility in Lapland and to use the International MODIS Processing Package provided by the CIMSS.

Richard Frey gave a presentation entitled "MODIS Cloud Mask - Overview and Current Issues" at the Terra Cloud Mask Conference, University of Wisconsin-Madison, May 8 – 9, 2001.

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Riggs, G., D. Hall, and J. Key, 2001: Initial evaluation of MODIS sea ice products, Proceedings of the 58th Annual Meeting of the Eastern Snow Conference, Ottawa, Ontario, May 14-17, 2001, forthcoming.

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Yang, P., B-C. Gao, B. A. Baum, Y. X. Hu, W. J. Wiscombe, M. I. Mishchenko, D. M. Winker, and S. L. Nasiri, 2001: Asymptotic solutions for optical properties of large particles with strong absorption. *Applied Optics*, Vol. 40, 1532-1547.

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